§12. Measurement of Turbulence of PPCD and High Θ Plasmas in TPE-RX RFP by Using MIR

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A microwave imaging reflectometry (MIR) system has been developed to investigate the turbulence in the reversed field pinch (RFP) plasma in TPE-RX [1]. This diagnostic is based on the radar technique. The 2D imaging of the density fluctuation is measured by a large optical system and 4 by 4 detector array with high sensitivity. The amplitude and the phase fluctuations of the reflected wave are decomposed by a quadrature detector into three parts, such as amplitude (A), in-phase (I=A sin(φ)) and quadrature (Q=A cos(φ)).The microwave with the frequency of 20GHz in O-mode is used and the spatial resolution is 3.7cm both in the toroidal and poloidal directions.

The RFP configuration is generated by the relaxation process and sustained by the dynamo effect, which is caused by turbulences and instabilities [2]. The plasma current propagating only along the filed line is driven by the dynamo term (<δv x δB>) and the external field term ($E_{//}$), as $\eta j_{//}=E_{//}+\langle\delta v \times \delta B\rangle$. In the normal and high Θ ($\Theta=B_p(a)/\langle B_t\rangle$, Θ>1.6) plasma the dynamo is dominant. In the pulsed poloidal current drive (PPCD) plasma the $E_{//}$ is dominant. We expect that the turbulence is suppressed and good confinement will be obtained in PPCD plasma.

The turbulences between the PPCD and the high Θ plasmas are compared in this study. Figure 1 shows the power spectra of PPCD and high Θ plasmas. The PPCD plasma has the high fluctuation power in the low frequency range (f <50 kHz). The mode at about 20 kHz is observed in the negative frequency range. This mode is seen at about 30 kHz in the positive frequency range. Therefore, the frequency shift is about 10 kHz. In the high frequency range, the spectra of negative and positive frequencies are almost overlapping which means a symmetric spectrum. The high Θ plasma has the low fluctuation power with a broad profile in the low frequency range. The mode frequency is about 10 kHz in the negative frequency range. This mode is seen at about 70 kHz in the positive frequency range. Therefore, the frequency shift is about 60 kHz. The difference between negative and positive spectra is large, especially in the range of 30-200 kHz, which means an asymmetric spectrum in high Θ plasma.

It is interesting to find that the fluctuation power of high Θ plasma is about two times higher than the PPCD plasma in the high frequency range (f >300 kHz). Therefore, the high Θ plasma has a broad spectral profile. It suggests that the high Θ plasma is dominant by the high frequency fluctuations.

A model based on the Kirchhoff integral is used to explain the power spectrum [3]. The reflection signal is modified by the turbulence, plasma rotation and the curvature of the reflection surface. The curvature effect can be neglected due to the large aperture optical imaging in a relative small plasma region. The turbulence and Doppler shift will be considered in this simulation. The RMS amplitude of the fluctuations is used to define the turbulence. The Doppler Effect is similar as the backward scattering in the oblique incidence because the same incident angle to launch and receive the microwave beam is used in our MIR system. This effect is equivalent to the vertical shift of the plasma column.

Figure 2(a) shows the power spectra of low and high turbulences case without considering the plasma rotation. The spectrum shows a broad profile in the high turbulence case. The spectra of the negative and positive frequencies have the symmetric profiles. Figure 2(b) shows the power spectrum when the Doppler Effect is considered. The spectrum has a frequency shift leading to an asymmetric spectral profile. Therefore, the broad spectral profile is caused by turbulences and the asymmetric spectral profile is caused by the Doppler Effect. This simulation confirms that the high Θ plasma has strong turbulence with fast velocity.

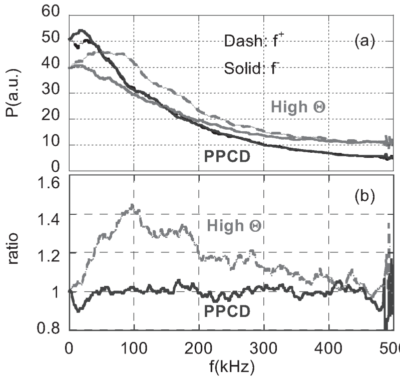

Fig. 1, (a) Spectra of IQ signals in PPCD and high Θ plasmas. The solid and dash lines represent negative and positive frequency spectra, respectively. (b) The ratios between positive and negative spectra of PPCD and high Θ plasmas.

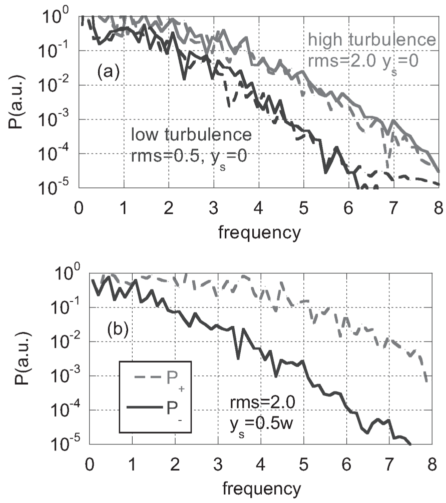

Fig. 2, power spectrum affected by (a) turbulence and (b) Doppler shift. The solid and dash lines represent negative and positive frequency spectra, respectively.

[1] Y. Nagayama, et al., submitted to PFR (2008).
[2] H.A.B. Bodin, Nuclear Fusion, **30**, 1717 (1990).
[3] A. Ejiri, etal, Plasma Phys. Control. Fusion, **50,** 065003 (2008).